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6 MeV X-band On-axis Standing Wave Linear Accelerator[1]

Xiang Sun
High Energy Physics Division
Argonne National Laboratory

Abstract

A portable X-band on-axis standing wave electron linear accelerator has been developed that is suitable for portable radiation therapy and radiography. The phase-focusing technique is used. The design parameters of a 6 MeV X-band on-axis SW accelerating guide, magnetron, thermionic cathode and four-port circulator are described. This accelerator system operates in π/2 mode and its frequency is 9300MHz. A prototype 380 mm long structure has been machined, brazed and sealed, and tested.

INTRODUCTION

The many advantages of using higher RF frequencies for electron linear accelerators include higher shunt impedance, higher breakdown threshold level, smaller size and short fill time. In addition, increasing the RF frequency increases the accelerated beam energy for a fixed input RF power. An extremely small accelerator structure with high shunt impedance is needed for medical, science research and industrial applications.

The schematic illustration of the accelerator is shown in Fig. 1.

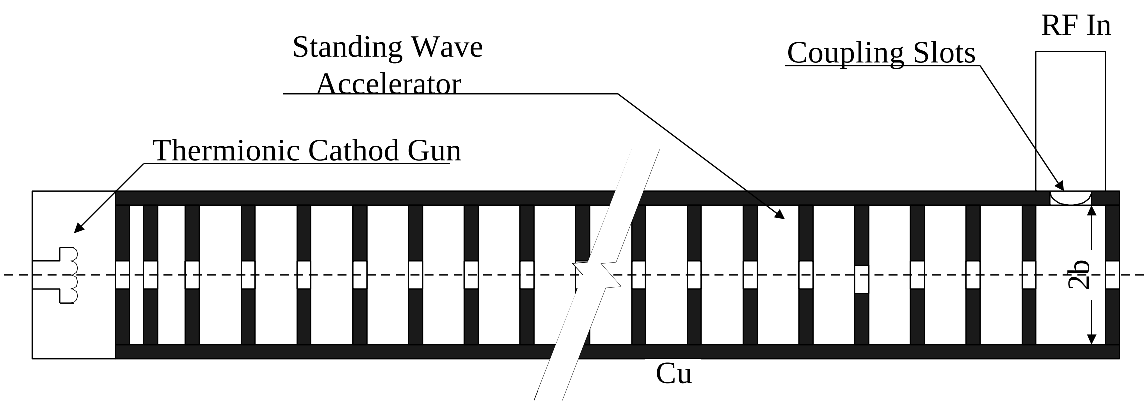

Fig. 1 schematic illustration of the accelerator

STRUCTURE OPTIMIZATION

Three types of X-band accelerator structures have been developed, the disc-loaded structure, the side-coupled structure, and the coaxially coupled structure. The

[1] This paper summarizes the work I have done at Tsinghua University, China. This work was bases of my Ph.D. Dissertation

effective shunt impedance of the on-axis structure is more than for the disc-loaded structure. Although the theoretical effective shunt impedance of the on-axis structure is less than for the side-coupled structure, our experience shows that the actual shunt impedance of both structures are similar with S-band linacs. The on-axis structure has advantages similar to the coaxially coupled structure that offers a significantly smaller diameter than the side-coupled structure. In addition to small size and less weight, the cylindrical symmetry structure is simpler to machine and braze. So we choice the on-axis structure as our accelerating structure.

The two important limits that influence the effective shunt impedance are the beam aperture radius and the thickness of the copper web between the accelerating cavities. Decreasing the beam aperture radius and the thickness of the copper web increases the effective shunt impedance. However, the size of the beam hole is limited by the beam transverse transmission. Our dynamic simulation calculations showed that the beam aperture diameter should be 3.5 mm. The web thickness is related to the coupling cavity that must be inserted between the two accelerating cavities in the on-axis coupled structure and to thermal conductivity requirements. The web thickness was chosen to be 2.8 mm and the coupling cell length was chosen to be 1.0 mm.

PHYSICAL DESIGN

A 6 MeV X-band on-axis SW accelerator was designed with a guide that is approximately 380 mm long. The structure is operated in the $\pi/2$ mode with an average effective shunt impedance of 143 MΩ/m. The RF power is supplied by a tunable coaxial magnetron of 1.5 MW peak power at X-band (9300 MHz). To minimize the size and weight of the structure and to improve the beam spot as well as the transmission, the phase-focusing technique was used without a bulky, external magnetic focusing device. It is well known in alternating phase focusing, that the electrons alternate between ahead of the accelerating crest where they are longitudinally focused and behind the crest where they are transverse focused. By choosing the right phase velocity taper and by tapering the magnitude of the buncher field levels from cavity to cavity, the RF field in the buncher region provides transverse focusing as well as longitudinal bunching and acceleration. An injection voltage of 14 kV is used with a converging injection beam. The electron beam focal spot size is less than 1.8 mm and the pulsed beam current is 50 mA with 1.2 MW input RF power. Some performance data for the system is shown following.

Injector (which has been sealed at the end of the accelerator, shown in Fig. 2):

Thermionic Cathode;
Emittance = 37.5 mm.mrad;
Injection Voltage V = 14 – 17 kV;
Coefficient = 0.22×10^{-6} A/V$^{3/2}$

X-band 6 Mev on-axis coupled accelerating guide (shown in Fig. 2):

Frequency f = 9300 MHz;
Beam Energy = 6 MeV;

Current = 50 mA (design);
Current = 7.3 mA (hot test);
Length = 380 mm;
Beam Focal Spot Size < 1.8 mm

Fig. 2. X-band 6 Mev on-axis SW guide Brazes Assembly

RF Power Source (shown in Fig. 3):

Magnetron;
P = 1.5 MW;
f_0 = 9300 MHz

Fig. 3. X-band 1.5 MW magnetron

Four-port Circulator (shown in Fig. 4):

Separation > 30 dB;
Attenuation < 0.5 dB;
SWR < 1.05

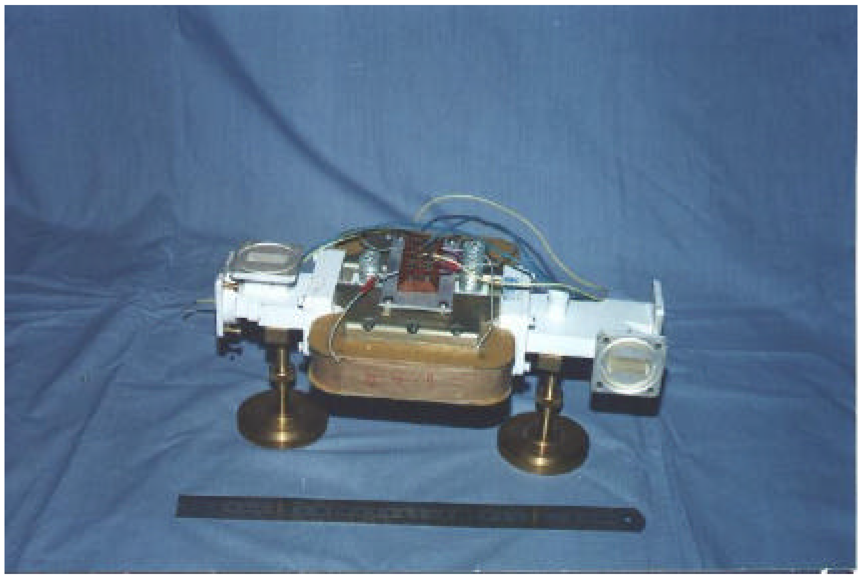

Fig. 4. X-band four-port circulator

TUNING AND TESTS

After careful machining, the cavities were assembled and tuned. The fabrication and tuning of the prototype X-band structure were strongly interrelated and must progress carefully due to the high operating frequency.

The overall structure was then brazed, evacuated and sealed. No post-braze tuning of the guide was done. The final measured Q for the guide is 6800. The average shunt impedance for the whole guide is about 143 MΩ/m. The beam energy is 6 MeV and the beam current is 7.3 mA. The hot test will be further extended to get design beam.